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THE USE OF A SMALL DIGITAL COMPUTER FOR ON-LINE BEHAVIORAL EXPERIMENTS

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SUMMARY PAGE

THE PROBLEM

Behavioral experiments solely relying on electromechanical and solid state devices for experiment control and data acquisition present special logistical problems and laborious data reduction tasks. Using small digital computers to control experiments and collect and analyze data allows multiple experiments to be conducted, and greatly enhances the speed and accuracy of data acquisition, reduction, and analysis.

FINDINGS

A Digital Equipment Corporation PDP-8a minicomputer was satisfactorily used for a behavioral experiment to control the experiment, collect and process data, and retrieve data from the computer's storage area.

ACKNOWLEDGMENTS

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INTRODUCTION

Behavioral experiments with performing animals have traditionally relied on electronic and electromechanical instrumentation to control experiments and acquire behavioral data. However, the logic circuitry required in such control functions is often difficult to implement, and the data must be manually extracted from counters or chart records. Also, in many cases, a transformation of the measurements must be made to obtain the final results. The development of computers has provided a more economical and expedient basis for experiment control and the acquisition, retrieval, and analysis of experimental data.

Computer software development for data handling and control of experiments was reviewed recently in a report by Blick *et al*. (1). This report indicates that a majority of current software systems for experiment control and data handling are based upon state notation language, and the most widely used system is SKED (6). The SKED program was developed in 1966 as a paper tape system for use with Digital Equipment Corporation PDP-8 computers, and extended in 1978 for use with the OS/8 operating system and mass storage devices. The state notation system, described by Snapper, Knapp and Kushner (7), is based on the theory of finite automata. Blick *et al*. (1) developed a modification of SKED (called MANX), for use with NOVA computers (Data General Corporation).

This report describes a computer system for behavioral experiments to control the experiment, acquire measurements, transform measurements into useable form, store measurements on disc files, and extract and analyze data. This application used a Digital Equipment Corporation PDP-8a minicomputer and the SKED™ (State Systems, Inc. Kalamazoo, Michigan) state notation software system (6) to provide the experiment control and data acquisition. Software was developed to analyze analogue measurements and convert these measurements prior to storage. Finally, a data storage and retrieval system (DSRS) was developed to provide a common data base for storage, extraction, analysis, and output of results.

The use of a commercially available state-notation software package significantly reduced the labor cost of software development and allowed experiments to go on line almost immediately. The interval-event measurement capability of the SKED system was utilized to develop a practical method of acquiring analogue measurements thereby extending the measurement capabilities of SKED to include physiological and environmental measurements. Since behavioral experiments typically produce large amounts of data, the development of a data retrieval and analysis system was considered essential for rapid generation of results.

This system increased the speed and accuracy of behavioral measurements, allowed multiple experiments to be conducted, and provided a capability for analogue measurements. The retrieval and analysis capabilities have reduced the manual operations considerably.

COMPUTER FACILITIES AND SOFTWARE

The PDP-8a minicomputer configuration in our laboratory consists of a 12-bit central processing unit with 32,000 words of core memory, two hard disc storage devices, a cathode ray tube (CRT) console, a printer, a paper tape reader, an incremental plotter, and the SKED interface hardware unit. The PDP-8a software includes the OS/8 operating system and the RTS/8 real time operating system. Application software is composed of the SKED Software System, the EVENT analogue conversion program, and the DSRS program. Figure 1 is a block diagram of the computer system connected to an experiment.

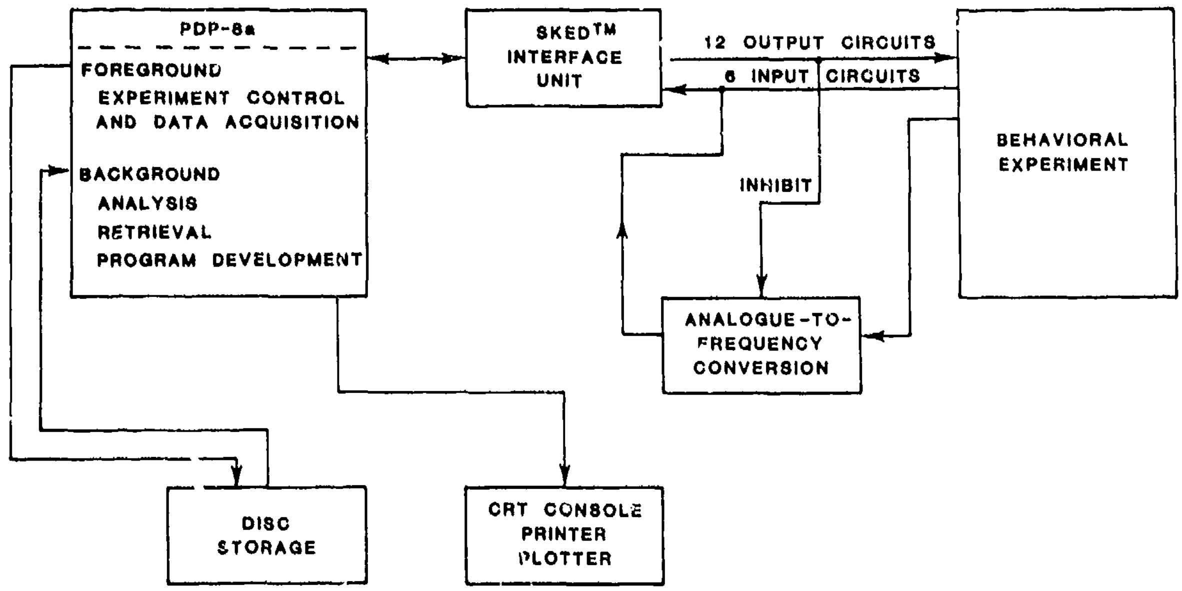

Figure 1

Block diagram of PDP-8a computer application to a behavioral experiment. The system is capable of handling 4 behavioral experiments at one time and a total of 48 output circuits and 24 input circuits.

The OS/8 operating system provides the means to compile, load, and run programs, create and edit source files, and manage data and program disc files. The RTS/8 real time operating system partitions the system into foreground and background areas. In this configuration, the OS/8 operating system runs in the background as a task of the RTS/8. This division allows the experiment-controlling functions under SKED to operate in the foreground and therefore have priority over the background tasks; data is either taken or control is issued immediately without waiting for another program to complete. Data analysis, program development, or file operations can proceed in the background simultaneously without interfering with the SKED experiment functions.

Due to the partitioning of the computer memory, the 32,000-word core memory size insures sufficient memory for each partition. The dual disc storage units have sufficient capacity to store the numerous data and program files, and essential data and programs can be copied periodically to insure data and program backup in the event of disc failures. The incremental plotter serves as an analysis tool.

The SKED software package requires a hardware interface unit to provide input and output connections to four behavioral experiments. The interface consists of four assemblies of input/output relays. Each assembly (box) has 6 data input connections and 12 output (experimental control) connections that join the computer to each behavioral experiment.

The SKED state notation program system (6) provides a language by which the experimenter can describe the process of the experiment. State notation is used to describe sequential events in which an output is determined by the current input and the preceding set of inputs. The resulting state table fully describes the schedule, or sequence, of the experiment including control functions, data acquisition, and time tables. Once entered into the computer, the state table can be compiled and then started from the console or from remote signals of the experiment. The SKED program will request subject, experiment, and group identifications and may be run on any or all of the experiment boxes.

An analogue conversion program (EVENT) is used to analyze interval-event data collected from the experiment by the SKED software and convert the data into interval or analogue data suitable for including in a data file. This program is specifically designed for each individual experiment and, consequently, several versions of the EVENT program exist to handle different experimental protocols. However, the final data is converted into a common form suitable for retrieval by the DSRS.

The DSRS was developed to extract, analyze and output the data collected from the experiments. Since this system must be able to handle all data, either event or analogue, a common data base was needed for data compatibility between the SKED, EVENT, and the DSRS programs.

EXPERIMENTAL CONTROL AND DATA ACQUISITION

The control functions of an experiment, output by the SKED state table, are effected through one or more of the 12 output relays. These relays are connected to the experiment instrumentation to perform control functions. In some cases, these control functions are used to initiate data input operations.

Input data consists of contact closures designating an event operated from the experiment instrumentation. The SKED program detects these events when they occur, records the number of the channel causing the event, and stores the data in one of two formats: (a) event data in which events are accumulated in a counter or (b) interval-event data in which the time (in tens of milliseconds) between two successive events is stored as data. The record identification designates one of 15 variables being measured. RECORD 0 is reserved to indicate accumulated counts of discrete events. The SKED state table can hold as many as 69 different accumulated events, and all 69 counters are designated as RECORD 0 while the different counters are identified from their sequential position. Interval-event data may be used to record time intervals or delays between two experiment events.

At the conclusion of the experiment, the data is stored in a named data file on the disc storage device. A SKED utility program, PIPI, is then run to convert the data from its temporary format to its final format. If the data was acquired in the event format, it is in the correct form to be accessed by the DSRS software. If the data was acquired in the interval-event format, then it must be analyzed by the EVENT program to convert the data into the correct format.

The interval-event acquisition capabilities of the SKED program provide a means of acquiring analogue measurements of physiological data such as heart rate and temperature. The analogue data to be measured must be converted into frequency so that the interval-event acquisition can detect the period of the signal. The period is then acquired and stored by the SKED program. Heart rate information, acquired by means of a cardiotachometer, can be directly applied to the input since the cardiotachometer detects the QRS complex and emits a pulse. The period between the QRS complexes is a measure of the heart rate. In the case of analogue data, an analogue-to-frequency converter (model VO-451, BRS/LVE, Beltsville, Maryland) is used to convert the analogue input to an output frequency. The unit can be calibrated to provide a known output frequency for a range of input voltage levels. Figure 2 is a block diagram of both the heart rate measurement and analogue to digital conversion of temperature measurement. The inhibit line is one of the 12 output relays and is used to control the acquisition of analogue measurements.

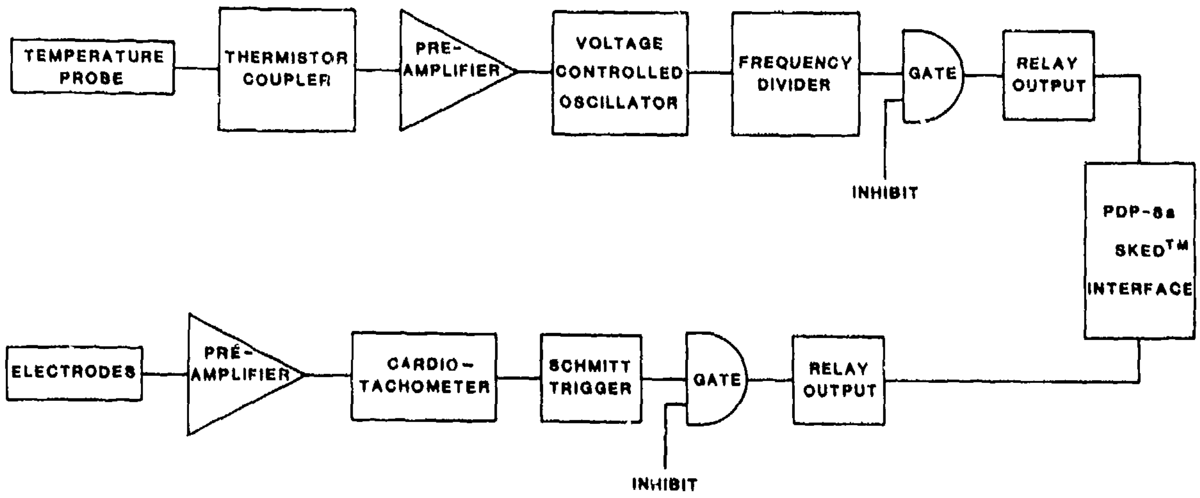

Figure 2

Block diagram of the analogue to digital conversion instrumentation for temperature and heart rate measurements.

PROCESSING OF INTERVAL-EVENT DATA

Data acquired in the interval-event data format to represent analogue voltages must be converted into its analogue equivalent using a suitable equation that relates the input and output of the analogue to voltage converter. In many cases, the relationship is nonlinear and it is necessary to express this relationship with second order equations. In addition, the manner in which the data is acquired and the method of interpretation are dependent on experimental conditions.

Typically, the measurement of analogue or interval-event data requires replicate measurements from which a mean value is calculated to provide a final datum to be stored in the data file. The EVENT program processes the interval-event data, converts the analogue data into its analogue equivalent, separates the data according to the record identification, partitions the data into the proper time periods, computes the particular variable, calculates the mean value, and finally stores the data into a named data file. Optionally, the EVENT program will print a summary of the raw data found, the number of samples found, and the mean value for each time period.

Another function of the EVENT program, used in heart rate measurements, is artifact detection and elimination. Heart rate measurements are subject to artifacts due to animal movement. The primary method of eliminating such artifacts is to acquire data during a quiescent period, which can be controlled by the data acquisition schedule. Another method, used in conjunction with the first, consists of electronic filtering or analysis techniques to eliminate spurious responses. A cardiotachometer detects the cardiac cycle QRS complex quite reliably even in the presence of some noise. However, excessive noise may cause spurious responses not related to the heart rate. The noise generated by a cardiotachometer usually results in double or skipped QRS events which result in measurements at twice or one-half the actual heart rate. An autocorrelation technique has been devised that identifies absurd values in the heart rate measurements by locating such measurements and rejecting them from the data before computing the mean values.

The autocorrelation algorithm technique for heart rate is based on a square array in which each row and each column of the array has a number of elements equal to the number of heart rate samples. An example in which 8 samples were recorded is shown in Table I. A ratio for each element is calculated by dividing the row's heart rate by the column's heart rate, and this ratio is inserted into the array element. This results in the diagonal of the array having a ratio of one and the elements off the diagonal having a ratio which relates each heart rate measurement to every other heart rate measurement. The rows of the array are then scanned and the number of ratios that are above .67 and below 1.33 are counted (these limits are adjustable but the limits of .67 and 1.33 have been found to be effective). In Table I, these ratio counts are shown to the right of the square array. The counts for each row are then compared and those rows having maximum counts are selected and the corresponding column heart rates are used to calculate the mean heart rate for that period. The selected heart rates are indicated by an asterisk.

An evaluation of the effectiveness of this autocorrelation technique was made by comparing the actual electrocardiogram (ECG) with the selected heart rates from the algorithm. From the actual ECG, the QRS complex can usually be recognized regardless of errors in the cardiotachometer. For the basis of the test, the ECG was classified by the percentage of the recording span that contained movement artifact. For example, an ECG that contained 50 percent of its signal as movement artifact would be classified as containing 50 percent noise. It was estimated that an ECG signal that contained no more than 25 percent noise could be corrected by the autocorrelation technique (artifact removed) and result in a final determination of not more

Table I

Autocorrelation array of heart rate ratios

Sequential heart rates (BPM) recorded during a minute

	120	135	119	110	142	240	92	130	Ratio Frequency > .67 AND < 1.33
120*	1	1.13	.99	.92	1.18	2.00	.77	1.08	7
135*	.89	1	.88	.81	1.05	1.78	.68	.96	7
119*	1.01	1.13	1	.92	1.19	2.02	.77	1.09	7
110*	1.09	1.23	1.08	1	1.29	2.18	.84	1.18	7
142	.85	.95	.84	.77	1	1.69	.65	.92	6
240	.50	.56	.50	.46	.59	1	.38	.54	1
92	1.30	1.47	1.29	1.20	1.54	2.61	1	1.41	4
130*	.92	1.04	.92	.85	1.09	1.85	.71	1	7

*Heart rates selected for calculation of mean ($\bar{x}$ = 123 BPM)

than 10 percent error with the usual case being less than 5 percent error. However, ECG signals that contain 50 per cent or more noise cause the rejection rate to decrease because the algorithm tends to accept a larger percent of the heart rate measurements even though they are in error. Moreover, it was found that if the heart rate actually undergoes a large level shift during the recording span, the algorithm may discriminate against the less prominent rate and reject these data. Scher *et al.* (5) have emphasized that there is increased need for careful and detailed attention to record quality when using a computer processing system.

RETRIEVAL AND ANALYSIS OF DATA

Data stored by the SKED program or by the EVENT programs are available for retrievel by the DSRS. This system provides a way to retrieve data, generate data sets, statistically analyze the data, and produce outputs on the CRT, printer, or plotter. The system accepts directives typed on the console keyboard in which the user specifies the operations, output devices, variables, and data files to be used. The system provides such functions as raw data, mean and standard deviations, frequency distributions, correlations, and statistical tests.

A common data format was adopted based on the storage conventions of the SKED program. Data can be stored in the range of 0 to 4095 with negative numbers not allowed. The value of 4095 was used to designate a missing value. Although the SKED program never detects a missing value, the EVENT programs may generate a missing data code if, for example, a recording span contains no data samples. The DSRS will detect missing data values and omit them from the calculations. In addition, the SKED and the EVENT programs store data with a channel identification. The channel is designated as the RECORD. Since many variables must be stored as real numbers (a number containing decimal places) a convention was adopted in which certain RECORD designations were assigned as integer, meaning that the range of values is 0 to 4094, and other records assigned as real, meaning that the datum contains an implied decimal point with a range of 0 to 409.4. The DSRS automatically sets the variable retrieval from a data file as integer or real depending on the RECORD.

The DSRS provides three primary operations: extraction of data from an on-going experiment, management of an experiment directory, and data extraction and set generation from data files. To monitor the status of an on-going experiment, the DSRS accesses the behavioral program in operation and reports the values currently held in its counters.

An investigator may generate a directory of data files containing group, experiment, subject, and box identifications for each data file in an experiment. With this information, the DSRS can access the directory, locate certain data files or data file sets by the attributes specified for group, experiment, subject, and box, and generate a list of file names to be operated upon. If the directive specifies file names, the directory is not used. However, if a request for output does not explicitly state a data file name, the DSRS goes to the directory to find the file names. To generate a directory, the investigator requests DSRS to insert a data file into the directory. DSRS then accesses the data file, extracts the identification information, and places it in the directory. Normally, the directory is generated after an experiment has been concluded to insure that only valid data files are used.

To extract data from the data files, the operation, output device, variable, counter sequence, and data files to be accessed must be given. For example, the directive PRINT MEANS RECORD 2 COUNTER 1-30 DATA.DA,DATA2.DA is a request to print the means for variable 2 from the data files DATA.DA and DATA2.DA for the sequence of counters from 1 through 30. The counter sequence refers to sequential measurements of the same variable. Alternatively, the directive may request an output by attribute. For example, the directive PRINT MEANS RECORD 2 COUNTER 1-30 GROUP 3,4 EXPERIMENT 2, BOX 0 would print the means for variable 2 counters 1-30 for all data files in the directory for group 3 and 4 and experiment 2, Box 0. Since the subject was not specified in this directive, DSRS would accept any subject number.

The summary statistics output includes means, standard deviations, and standard error of the mean computations. The frequency distribution consists of the number of counts found within a subclass. The class limits are defined for each variable within the system according to the RECORD assignments, and defaults to 10 subclasses. However, the number of subclasses may be included in the directive. Correlations between groups consist of Pearson product-moment correlation coefficients between the means of two groups of data files. Two Student t-tests are provided; a non-correlated t-test, in which the subjects in the two groups are independent, and a correlated t-test, in which the subjects are repeated between the two groups. The mean, standard deviation, and number of samples for each group, or the mean, standard deviation, and number of samples for the differences between the two groups, are produced along with the t-statistic and its significance level.

More than one group of files may be specified for any operation. For example, a request to plot the means of two groups will produce a graph with the means of both groups plotted with different symbols to separate the groups. The correlation and t-test require that two groups be used, while multiple groups for the other operations are optional. If the directive includes the keyword FACTOR n, where n is the number of groups, DSRS will generate the first set of data, and return to the keyboard to allow the specifications for the next group to be entered.

The design of many behavioral experiments involves more than a single factor and requires more sophisticated statistical analysis then a simple test. An analysis of variance (ANOVA) has been included in the DSRS to provide statistical testing of either independent measures or repeated measures on subjects. The repeated measures design, the most widely used in behavioral measures, is described by Harter and Lum (2) and Winer (8). The DSRS extracts the variables from the data base and generates an ANOVA data file. An analysis program then retrieves the data and performs the analysis of variance consisting of a summary of the cell (subject replications) means, correlated t tests between subject cells, an ANOVA summary table, and a summary of the means for the factor terms in the ANOVA.

AN EXAMPLE OF A COMPUTERIZED MICROWAVE BEHAVIORAL EXPERIMENT

To illustrate the use of this system, an actual experiment is described. The object of the experiment was to determine if the behavior of rhesus monkeys exposed to microwave radiation differ from their behavior in a sham exposure. The state table, which describes the experiment process, was started under control of the SKED program and directed both the experiment control and the acquisition of data for a single subject. Seven data measurements (RECORD 0-5 and RECORD 9) were taken; Accumulative event counts; correct responses, post reinforcement responses, heart rate, colonic temperature, ambient temperature, and number of food pellet reinforcements. Appendix A contains a description of these measurement variables and the derived variables for RECORD 6-8.

Figure 3 is a block diagram showing the relationship of the experiment to the computer. Details of the microwave exposure situation are in other reports (3, 4). Essentially, a male rhesus monkey (Macaca mulatta) was

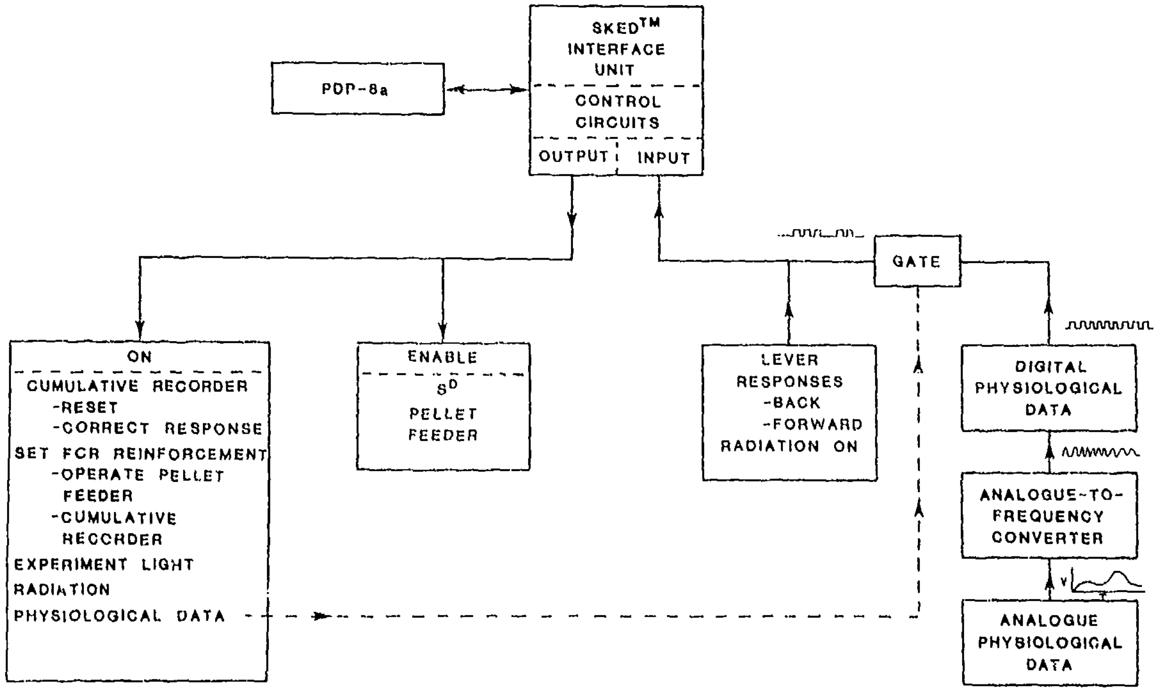

Figure 3

Block diagram of exercise experiment and its relationship to a computer.

restrained in an exercise chair which was designed for him to receive a food pellet reinforcement after making a number of lever responses. The rhesus monkey was prepared prior to each behavioral session for electrocardiography and colonic temperature measurements. The effects of microwave radiation were judged by comparing control session data with radiation session data collected and analyzed by the computer programs. The output circuits (see Figure 1) of the SKED Interface Unit controlled the experiment and data was acquired by the computer from the input circuits.

Output circuits delivered pulses from the computer to the experiment that switched on the experiment light, set the food dispenser for reinforcement, enabled an audible tone that indicated a complete to-and-fro lever response had been made, commenced the radiation, enabled the food pellet dispenser, activated temperature and heart rate frequency pulses to the computer, energized the cumulative recorder, and sent a signal to the cumulative recorder each time a response was made or a pellet reinforcement was delivered.

Input circuits from the experiment to the computer indicated when responses were made, when radiation was on, and when physiological responses occurred. The SKED program accumulated any RECORD 0 counts over the entire experiment, and stored both the record number and the time of occurrence of any RECORD 1-5 responses. This process continued until the experiment ended.

Figure 4 depicts the time sequence and conditions used in the experiment. It was composed of 8 components: pre-session, 3 extinction, 3 exercise, and post-session.

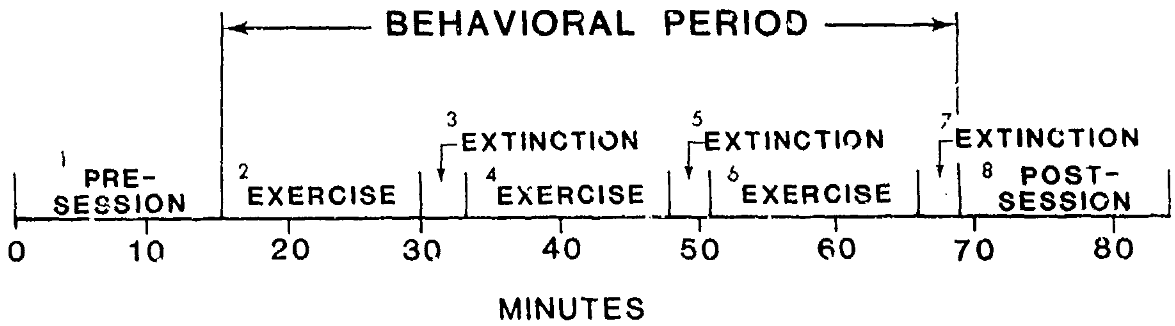

Figure 4

The time sequence for an experiment in which rhesus monkeys exercised at three different levels. During the non-exercising components there were no food pellet reinforcements, correct response signals, or lights on. Each component of the schedule is identified by a superscript number.

DATA REDUCTION

After the experiment was concluded, the EVENT program was then started to analyze the raw interval-event data contained in the disc data file, and produced a file in which the interval-event times and responses were converted into meaningful data and separated into minutes and components of the daily experiment session. Appendix A contains a description and example printout (Figure A2) of the analysis. The program extracted the time interval between events (stored in 0.01 second increments), determined the record type, and converted the interval into the resultant datum, computing either response times, heart rates, or temperatures. For each minute, the mean values of RECORDS 1-5 and RECORD 9 were calculated and stored. At the end of each component, RECORDS 6-8 were derived from RECORDS 1-3 as the mean over the previous component. The resultant data file contains both the record number and its mean measure, and is ready to be accessed by the DSRS program for final inspection, analysis, or plotting. Example printouts of a raw data listing and a mean computation are shown in Appendix A, Figures A3 and A4. Since this experiment lasted 84 minutes and was separated into 8 components, RECORDS 1-5 and RECORD 9 have 84 measures and RECORDS 6-8 have 8 measures.

CONCLUSION

A Digital Equipment Corporation PDP-8a was satisfactorily used to conduct a behavioral experiment, and analyze data to evaluate behavioral and physiological microwave effects. Our experience with this system has shown that the speed and accuracy of the behavioral measurements has significantly increased, that multiple experiments can be operated satisfactorily, and that analog measurements of physiological data are practical using the SKED software system. In addition, the disc storage of the data provides a convenient retrieval and analysis environment.

Some drawbacks of the system were found to be that the inherent 0.01 second resolution of the SKED system limited the accuracy of analogue measurements, and that the single console limited communications with programs to either the foreground or background with the consequence that background operations (such as analysis or program development) had to be terminated in order to communicate with the SKED program. Since some of the analogue measurement conversions take 30 minutes or more, timing of the analysis had to be coordinated with the startup of experiments. In addition, it was found that the SKED system could acquire large amounts of data from a large number of experimental sessions with the consequence that the basic limitation of 240 OS/8 directory entries limited the storage of data files. This required careful management of the data files, combining files where practical, and transferring interval-event raw data files (which were quite lengthy) to backup disc for permanent storage.

REFERENCES

1. Blick, D. W., Yates, J.T., and Wheeler, T.G., MANX: A system for computerized control of and data acquisition from behavioral experiments. Report SAM-TR-82-6. Brooks Air Force Base, TX: USAF School of Aero space Medicine, 1982.

2. Harter, H. L., and Lum, Mary D., Partially Hierarchal Models in the Analysis of Variance. WADC Technical Report 55-33, March 1955, p 118.

3. Knepton, J., de Lorge, J., and Griner, T., Effects of pulsed microwaves at 1.28 and 5.62 GHz on rhesus monkeys (*Macaca mulatta*) performing an exercise task at three levels of work. NAMRL Technical Report, NAMRL-1293. Naval Aerospace Medical Research Laboratory, Pensacola, FL, 1983.

4. Knepton, J., Ezell, C., and de Lorge, J., A restraint chair with rowing-like movement for exposing exercising nonhuman primates to microwave irradiation. NAMRL Technical Report, NAMRL-1298. Naval Aerospace Medical Research Laboratory, Pensacola, FL, 1983.

5. Scher, A.M., Ohm, W.W., Kehl, T.H., and Young, A.C., Computer data collection and editing for hemodynamic studies. Ann. Biomed. Eng. 1(1): 99-114, 1972.

6. Snapper, A.G., and Inglis, G.B., SKED Software System (Manual 3): Time Shared SUPERSKED. Kalamazoo, Michigan: State Systems, Inc., 1979.

7. Snapper, A.G., Knapp, J.Z., and Kushner, H.K., Mathematical description of schedules of reinforcement: In: Schoenfeld,, W.N. (Ed.), The Theory of Reinforcement Schedules. New York: Appleton-Century-Crafts, 1970, Pp 247-275.

8. Winer, B.J., Statistical principles in experimental design. Mcgraw-Hill Book Company, NY; 1962, Pp 289-290.

APPENDIX A

DESCRIPTION OF MEASUREMENT VARIABLES FOR THE EXAMPLE MICROWAVE BEHAVIORAL EXPERIMENT, AND TYPICAL PRINTOUTS OF THE ANALYSIS OF INTERVAL-EVENT MEASUREMENTS, THE RETRIEVAL OF RAW DATA, AND MEAN COMPUTATIONS

In the example experiment, seven measurement variables (RECORDS 0-5 and RECORD 9) were acquired and are described below. RECORDS 6-8 are derived variables.

Record 0: The SKED™ "C-array". This record accumulates event counts as they occur. Twelve of the 69 available counters were used; correct responses, incorrect responses, pellet reinforcement, and time in session (minutes). No conversion or computation was involved.

Record 1: Correct responses each minute. Within a minute, up to 100 correct responses were stored, and any greater number of responses was ignored. The most responses produced by an exercising subject in a single minute was 80, however, the usual maximum number of responses during a minute was about 60.

Record 2: Mean post-reinforcement pause time each minute (PRfPT). The PRfPT was the time in seconds between delivery of a food pellet reinforcement and the next correct response. Within a minute, up to 30 PRfPT's were stored, and any greater number of PRfPT's was ignored. The PRfPT's and mean PRfPT of each minute were recorded. If the correct response following a reinforcement extended into other minutes, the results were recorded in the appropriate minute.

Record 3: Heart rate. During each minute as many as 20 samples of heart rate were stored. Sampling was done for 10 seconds at the beginning of each session minute and 10 seconds following a food pellet reinforcement. Each sample was calculated in beats per minute (BPM) and was stored as three significant digits with fractions rounded to the next full beat. These samples were then subjected to serial correlation (autocorrelation) in which an effort was made to eliminate absurd heart rate values.

Record 4: Colonic temperature. During a minute a maximum of 30 temperature samples could be accepted by the computer. Samples were delivered to the computer each session-minute for 10 seconds starting with the 30th second. The algorithm's calculated temperature resolution was .01 °C. The computer conversion of interval-event time is based on the equation $Y=Ax^B$ where coefficients A and B were determined by fitting calibration curve data points. The coefficients may be changed if the calibration curve changes. Y is the temperature to be determined from the measured interval-event time X. The calibration curve of Figure A1 is the one used for the RECORD 4 algorithm. The calibration curve was obtained by substituting a temperature probe immersed in a constant temperature-controlled water bath for the probe normally used in a monkey's colon. At each temperature data point reading (abscissa value of Figure A1) the output of the frequency divider (abscissa in parentheses of Figure A1) was measured with a Hewlett-Packard 5302A Universal Counter. Then the time between pulses arriving in the computer (an interval-event) was calculated in hundredths of seconds (ordinate, Figure A1).

During an experimental session, routine comparisons were made between readings of a subject's colonic temperature on a YSI telethermometer Model 46 TUC (Yellow Springs Instrument Co., Yellow Springs, Ohio) and Figure A1 calibration curve data points. The usual difference was no greater than .1 °C.

Record 5: Ambient temperature. The method for ambient temperature was the same as for colonic temperature.

Record 6: Interresponse time (IRT): During each experimental component the times between responses were measured, separated, and accumulated into intervals from 0 to 10 seconds in increments of one second. An interval greater than 10 seconds was placed in the 10 second interval. At the end of a component an IRT histogram was derived by the EVENT program.

Record 7: Mean correct responses per minute (RPM) during each component. During a component, the number of correct responses was accumulated. At the end of a component, the mean number of correct responses for that component was calculated and stored.

Record 8: Mean post-reinforcement pause time (PRfPT) for each component. During a component the times between food pellet reinforcement and the next responses were accumulated. The mean PRfPT was computed and stored at the end of a component.

Record 9: Number of food pellet reinforcements each minute. During each minute the number of food pellet reinforcement pause times was accumulated and stored. This was retrieved from the computer data storage in terms of food pellets delivered to the subject during a minute.

An example of the interval-event analysis for the 30th minute is shown in Figure A2. Minute 30 of the experiment is the last minute in component 2 and a summary is included in which the derived variables are calculated. Twenty-nine correct responses were found and listed, and the interval average of those correct responses is calculated for RECORD 1 and stored. For RECORD 2, a single reinforcement was found and the interval was stored. For RECORD 3, heart rate, 14 valid heart rate measurements (as determined by the autocorrelation algorithm) were found and the mean heart rate was stored. For RECORD 4 and 5, three and five samples were found respectively, and the mean temperatures were stored. RECORD 9 is the number of reinforcements shown in RECORD 2.

The summary of component 2 distributes the correct responses of RECORD 1 for the previous 15 minutes into 10 one-second classes and stores these 10 values as RECORD 6. The mean number of correct responses for the previous component is calculated, listed, and stored as RECORD 7. RECORD 8 is calculated as the mean PRfPT of the previous 15 minutes and stored.

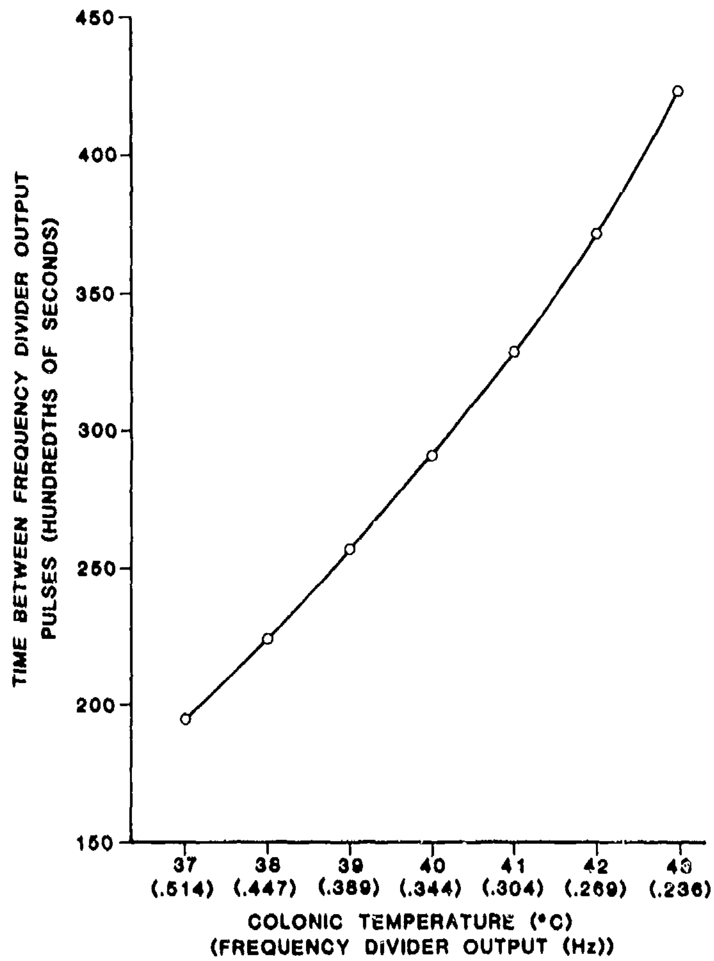

Figure A1

Colonic temperature probe calibration curve.

Figure A3 is a printout of the raw data for RECORD 4 (colonic temperature) in which each datum is the mean value calculated from the EVENT analysis of the original interval-event measurements. The print out details the data file name and parameters of the experiment.

Figure A4 is an example printout of a mean computation for RECORD 3 (heart rate) in which the mean is calculated from three subject data files. A missing sample was found at minute 46, indicating that no heart rate measurements were found in that minute for one of the subject data files.

```
MINUTE  30 TIME=  1800.02 SECONDS  COMPONENT  2

      RECORD 1          29 CORRECT RESPONSES
      INTERVAL AVERAGE:  2.01 SECONDS
       ( 1)   1.4 ( 2)   1.5 ( 3)   1.4 ( 4)   1.4 ( 5)   1.4 ( 6)   1.9 ( 7)   1.5 ( 8)   1.8 ( 9)   1.6 (10)   1.3
(11)   1.8 (12)   1.7 (13)   4.1 (14)   1.5 (15)   1.5 (16)   1.4 (17)   1.6 (18)   1.7 (19)   2.3 (20)   3.3
(21)   1.5 (22)   1.3 (23)   2.0 (24)   3.5 (25)   2.3 (26)   4.0 (27)   3.0 (28)   2.1 (29)   2.3 (

      RECORD 2           1 REINFORCEMENTS
      MEAN P/RT:  3.99 SECONDS
       ( 1)   4.0 (

      RECORD 3  HEARTRATE    14 SAMPLES USED
      MEAN HEARTRATE:  164.47 BPM
       ( 1) 153.9 ( 2) 176.6 ( 3) 171.5 ( 4) 176.6 ( 5) 162.3 ( 6) 162.2 ( 7) 157.9 ( 8) 187.6 ( 9) 146.4 (10) 153.9
(11) 146.4 (12) 181.9 (13) 153.9 (14) 171.6 (

      RECORD 4  COLONIC TEMPERATURE
           3 SAMPLES FOUND    MEAN: 38.67 DEG C
       ( 1)  38.7 ( 2)  38.7 ( 3)  38.7 (

      RECORD 5   AMBIENT TEMPERATURE
           5 SAMPLES FOUND     MEAN: 22.29 DEG C
       ( 1)  22.3 ( 2)  22.3 ( 3)  22.3 ( 4)  22.3 ( 5)  22.3 (

COMPONENT 2  SUMMARY

      HISTOGRAM OF CORRECT RESPONSES
       ( 1)   0.0 ( 2) 295.0 ( 3)  60.0 ( 4)  34.0 ( 5)  14.0 ( 6)   7.0 ( 7)   2.0 ( 8)   3.0 ( 9)   1.0 (10)   4.0

       28.00 CORRECT RESPONSES/MINUTE

       MEAN P/RT:   4.53 SECONDS    26 SAMPLES
```

Figure A2

Interval-event analysis of the 30th minute of the experiment.

```
RECORD      4 COUNTER  1- 84 PARAMETER    0

FILE# 281 RL1B: X16982.DA
BOX 2      3/10/1982
EXPERIMENT     103  SUBJECT      4  GROUP    61
RAW DATA
  1)  38.7 (  2)  38.7 (  3)  38.7 (  4)  38.7 (  5)  38.6 (  6)  38.7 (  7)  38.7 (  8)  38.7 (  9)  38.7 ( 10)  38.7
 11)  38.6 ( 12)  38.7 ( 13)  38.7 ( 14)  38.7 ( 15)  38.7 ( 16)  38.7 ( 17)  38.6 ( 18)  38.6 ( 19)  38.7 ( 20)  38.7
 21)  38.7 ( 22)  38.7 ( 23)  38.6 ( 24)  38.7 ( 25)  38.8 ( 26)  38.8 ( 27)  38.8 ( 28)  38.8 ( 29)  38.8 ( 30)  38.8
 31)  38.8 ( 32)  38.8 ( 33)  38.9 ( 34)  38.9 ( 35)  38.9 ( 36)  38.9 ( 37)  38.9 ( 38)  38.9 ( 39)  39.0 ( 40)  39.0
 41)  39.0 ( 42)  38.8 ( 43)  39.0 ( 44)  39.1 ( 45)  39.0 ( 46)  39.1 ( 47)  39.1 ( 48)  39.1 ( 49)  39.2 ( 50)  39.1
 51)  39.1 ( 52)  39.1 ( 53)  39.1 ( 54)  39.1 ( 55)  39.0 ( 56)  39.1 ( 57)  39.2 ( 58)  39.2 ( 59)  39.3 ( 60)  39.3
 61)  39.3 ( 62)  39.3 ( 63)  39.2 ( 64)  39.4 ( 65)  39.4 ( 66)  39.4 ( 67)  39.4 ( 68)  39.4 ( 69)  39.3 ( 70)  39.4
 71)  39.4 ( 72)  39.4 ( 73)  39.3 ( 74)  39.3 ( 75)  39.1 ( 76)  39.3 ( 77)  39.2 ( 78)  39.2 ( 79)  39.0 ( 80)  39.2
 81)  39.2 ( 82)  39.1 ( 83)  39.1 ( 84)  39.1 (
```

Figure A3

Colonic temperature of a subject for each of the 84 minutes in the experiment.

RECORD 3 COUNTER 1- 84 PARAMETER 0

FILE# 177 RL1B: X06582.DA
BOX 2 1/27/1982
EXPERIMENT 77 SUBJECT 4 GROUP 41

FILE# 241 RL1B: X12982.DA
BOX 2 2/24/1982
EXPERIMENT 93 SUBJECT 4 GROUP 41

FILE# 293 RL1B: X18182.DA
BOX 2 3/15/1982
EXPERIMENT 106 SUBJECT 4 GROUP 41
GROUP 1 1 MISSING SAMPLES

SAMP	MEAN	STD DEV	SEM	NS
1	147.67	15.70	9.06	3
2	135.33	3.21	1.86	3
3	133.00	9.64	5.57	3
4	135.00	19.08	11.02	3
5	136.67	29.02	16.76	3
6	128.33	6.81	3.93	3
7	129.00	9.54	5.51	3
8	125.33	11.02	6.36	3
9	123.67	6.66	3.84	3
10	122.00	13.11	7.57	3
11	127.33	6.66	3.84	3
12	122.67	13.32	7.69	3
13	116.67	5.77	3.33	3
14	117.67	2.52	1.45	3
15	112.67	0.56	0.33	3
16	126.67	7.23	4.18	3
17	156.00	19.29	11.14	3
18	167.67	6.11	3.53	3
19	157.67	13.01	7.51	3
20	169.67	8.51	4.91	3
21	159.33	13.01	7.51	3
22	159.00	11.36	6.56	3
23	159.00	10.15	5.86	3
24	165.67	6.51	3.76	3
25	161.00	14.80	8.54	3
26	161.67	11.59	6.69	3
27	162.00	5.29	3.06	3
28	157.67	16.50	9.53	3
29	171.00	5.57	3.21	3
30	148.00	4.58	2.65	3
31	170.00	12.49	7.21	3
32	153.33	24.79	14.31	3
33	167.67	18.56	10.71	3
34	158.33	10.79	6.23	3
35	174.67	19.14	11.05	3
36	185.33	7.77	4.46	3
37	185.33	13.80	7.97	3
38	182.33	18.01	10.40	3
39	179.00	13.08	7.55	3
40	187.67	14.64	8.45	3
41	200.67	15.28	8.82	3
42	200.67	2.52	1.45	3
43	197.67	11.85	6.84	3
44	194.67	6.66	3.84	3
45	211.00	16.70	9.64	3
46	204.50	12.02	8.50	2
47	204.67	14.47	8.35	3
48	201.00	8.19	4.73	3
49	197.67	10.26	5.93	3
50	179.33	4.93	2.85	3
51	163.33	7.02	4.06	3
52	172.67	9.07	5.24	3
53	210.33	13.01	7.51	3
54	222.00	13.45	7.77	3
55	214.33	26.31	15.19	3
56	222.67	12.42	7.17	3
57	223.67	5.03	2.91	3
58	230.00	16.82	9.71	3
59	239.33	20.60	11.89	3
60	237.00	11.00	6.35	3
61	239.67	8.74	5.04	3
62	236.67	5.13	2.96	3
63	227.00	17.78	10.26	3
64	235.67	35.35	20.41	3
65	243.67	5.51	3.18	3
66	214.00	10.15	5.86	3
67	219.33	16.50	9.53	3
68	195.33	12.34	7.13	3
69	192.67	14.05	8.11	3
70	178.67	2.31	1.33	3
71	179.00	9.54	5.51	3
72	171.67	21.83	12.60	3
73	170.33	23.69	13.68	3
74	159.33	11.15	6.44	3
75	144.00	5.00	2.89	3
76	153.33	17.39	10.04	3
77	146.00	13.00	7.51	3
78	151.33	16.07	9.28	3
79	138.67	9.45	5.46	3
80	132.00	12.53	7.23	3
81	132.33	1.53	0.88	3
82	135.33	5.77	3.33	3
83	131.67	4.04	2.33	3
84	136.33	5.51	3.18	3

Figure A4

Mean heart rate of three subjects for each of the 84 minutes of the experiment.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A Digital Equipment Corporation PDP-8a minicomputer was used to control behavioral experiments, acquire digital and analogue measurements, transform measurements and store the results into a common data base, and retrieve and analyze the final data. The SKED software system was used to acquire data and control the experiments, and the interval-event capabilities of SKED were utilized to measure analogue signals. Software was developed to convert interval-event measurements into analogue data, analyze and format the data

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by experiment protocol, and analyze heart rate measurements to eliminate noise-induced artifact. A data storage and retrieval system was also developed to retrieve and analyze the final data with lists or plots of statistical summaries and provide statistical tests. This system significantly increased the speed and accuracy of behavioral measurements, allowed multiple experiments to be conducted concurrently, and provided convenient access to experimental data for inspection, analysis, and output. An actual experiment is described to illustrate the use of this system.